MILLIMETER WAVE ANTENNAS HAVING CONTINUOUSLY STACKED RADIATING ELEMENTS

BACKGROUND

[0001] This relates generally to electronic devices and, more particularly, to electronic devices with wireless communications circuitry.

[0002] Electronic devices often include wireless communications circuitry. For example, cellular telephones, computers, and other devices often contain antennas and wireless transceivers for supporting wireless communications.

[0003] It may be desirable to support wireless communications in millimeter wave and centimeter wave communications bands. Millimeter wave communications, which are sometimes referred to as extremely high frequency (EHF) communications, and centimeter wave communications involve communications at frequencies of about 10-300 GHz. In order to support millimeter and centimeter wave communications, an array of antennas is formed on a substrate. Transmission lines for the array are embedded within the substrate.

[0004] Operation at these frequencies may support high bandwidths but may raise significant challenges. For example, it can be difficult to ensure that transmission lines on the substrate are sufficiently isolated from each other, particularly as the number of antennas in the array increases. At the same time, manufacturers are continually striving to implement wireless communications circuitry such as antenna arrays using compact structures to satisfy consumer demand for small form factor wireless devices.

[0005] It would therefore be desirable to be able to provide electronic devices with improved wireless communications circuitry such as communications circuitry that supports millimeter and centimeter wave communications.

SUMMARY

[0006] An electronic device may be provided with wireless circuitry. The wireless circuitry may include radio-frequency transceiver circuitry and a phased antenna array. The phased antenna array may convey radio-frequency signals in a signal beam at a frequency greater than 10 GHz.

[0007] The phased antenna array may be formed on a dielectric substrate having vertically-stacked dielectric layers. The dielectric layers may include transmission line layers and antenna layers stacked on the transmission line layers. Ground traces may separate the transmission line layers from the antenna layers. The phased antenna array may include antennas having antenna radiating elements formed on the antenna layers. Fences of conductive vias may be used to isolate the antennas in the phased antenna array from each other. The phased antenna array may be mounted against a dielectric cover layer (e.g., a housing wall for the device) and may radiate through the dielectric cover layer.

[0008] An antenna in the phased antenna array may have an antenna radiating element that includes first, second, and third patch elements formed from overlapping conductive traces on the antenna layers. The first patch element may be interposed between the ground traces and the second patch element. The second patch element may be interposed between the first and third patch elements. The antenna may include parasitic elements that are formed from conductive traces coplanar with one or more of the first, second, and third patch elements. The antenna may be fed using a differential radio-frequency transmission line path coupled to a differential antenna feed on the first patch element. The differential radio-frequency transmission line path may include first and second strip lines having first and second signal traces, as an example.

[0009] A first conductive via may be used to couple the first signal trace to the first, second, and third patch elements. For example, the first conductive via may include a first portion that couples the first signal trace to the first patch element, a second portion that is laterally-aligned with the first portion and that couples the first patch element to the second patch element, and a third portion that is laterally-aligned with the first and second portions and that couples the second patch element to the third patch element. A second conductive via may similarly be used to couple the second signal trace to the first, second, and third patch elements. In another suitable arrangement, a single-ended antenna feed may be used.

[0010] The first, second, and third patch elements may introduce capacitances to the antenna radiating element that help to compensate for excessive inductances associated with the distance between the antenna radiating element and the signal traces of the radio-frequency transmission line path. This may ensure that the antenna is impedance matched to the radio-frequency transmission line path. If desired, the phased antenna array may include an additional antenna with an additional antenna radiating element that is fed using an additional radio-frequency transmission line path. The additional radio-frequency transmission line path may be located closer to the additional antenna radiating element in the transmission line layers than the radio-frequency transmission line path used to feed the antenna. The additional antenna radiating element may include only a single patch element formed from a single layer of conductive traces. By distributing the radio-frequency transmission line paths across multiple transmission line layers, the phased antenna array may include a large number of antennas, may cover a large number of frequencies, and/or may cover a large number of polarizations while also exhibiting sufficient electromagnetic isolation between the radio-frequency transmission line paths.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. **1** is a front perspective view of an illustrative electronic device with wireless circuitry in accordance with some embodiments.

[0012] FIG. **2** is a rear perspective view of an illustrative electronic device with wireless circuitry in accordance with some embodiments.

[0013] FIG. **3** is a schematic diagram of an illustrative electronic device with wireless circuitry in accordance with some embodiments.

[0014] FIG. **4** is a diagram of an illustrative phased antenna array that forms a radio-frequency signal beam at different beam pointing angles in accordance with some embodiments.

[0015] FIG. **5** is a diagram of an illustrative transceiver circuit and antenna in accordance with some embodiments.

[0016] FIG. **6** is a perspective view of an illustrative differentially-fed patch antenna in accordance with some embodiments.